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Analysis of Beliefs of Survivors of the 7/7 London Bombings: Application of a Formal Model for Contagion of Mental States

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Abstract. During emergency scenarios, the large number of possible influences *inter se* between cognitive and affective states of the individuals involved makes it difficult to analyse their (collective) behaviour. To study the behaviour of collectives of individuals during emergencies, this paper proposes a methodology based on formalisation of empirical transcripts and agent-based simulation, and applies this to a case study in the domain of the 7/7 London bombings in 2005. For this domain, first a number of survivor statements have been formalised. Next, an existing agent-based model has been applied to simulate the scenarios described in the statements. Via a formal comparison, the model was found capable of closely reproducing the real world scenarios.

Keywords: London bombings, agent-based simulation, contagion.

1 Introduction

During large-scale emergencies such as terrorist attacks or natural disasters, the involved persons may behave in unexpected ways. For example, some individuals may immediately start panicking and 'lose control over their actions', whereas others may emerge as 'calm leaders' helping other people. Especially in larger crowds, the numerous possible influences of mental states within individuals (e.g., person A has the belief that he will die, and therefore starts panicking) and between individuals (e.g., person B manages to calm down person A) makes it very difficult to predict how a certain crowd will behave in a particular situation. Nevertheless, gaining more insight into the dynamics of these processes is very useful, since it enables policy makers to explore possibilities for developing procedures and interventions that may minimise the number of casualties in such emergency scenarios (e.g., providing emergency exits at appropriate locations, or equipping patrollers with intelligent devices that recommend escape routes). In line with recent developments [2,13], this paper proposes to study such dynamics using agent-based simulations.

More specifically, to be able to analyse the dynamics of mental states and their intra- and interpersonal interaction in emergency scenarios, an agent-based simulation

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model ASCRIBE (Agent-based Social Contagion Regarding Intention Beliefs and Emotions) has been developed [9]. This model has been inspired by several concepts from Social Neuroscience [6,7], including the concepts of *mirror neuron* (i.e., a type of neuron that fires not only when an individual performs an action, but also when he/she observes this action performed by someone else [10,11]) and *somatic marker* (i.e., a feeling induced by a certain decision option considered by an individual, which helps the individual make decisions by biasing that option [1,7]). Based on these concepts, the ASCRIBE model describes how for different individuals in a crowd, the strength of their beliefs, intentions and emotions may evolve.

The main goal of the current paper is to show how the model can be used to analyse the dynamics of individuals' mental states for a real world incident. To this end, a case study is undertaken which analyses the London bombings of July 7th, 2005. To test the applicability of the model to this case, a research methodology is followed that consists of a number of steps. First, a set of survivor statements which were extracted from the 'Report of the 7 July Review Committee' [12], have been formalised using a dedicated ontology. Next, the ASCRIBE model has been applied to generate a number of simulation runs for fragments of the scenarios described in the survivor statements. And finally, the results of the simulations have been compared with the formalised survivor statements, both in an informal and in a formal manner (using an automated tool).

The remainder of this paper is organised as follows: Section 2 provides a brief description of the London bombings. Section 3 explains how statements of survivors of the attack were obtained and converted to formal notation. Section 4 summarises the main mechanisms of the ASCRIBE model and Section 5 shows how the model was applied to the London bombings scenario. Section 6 discusses the (formal) comparison between the simulation runs and the formalised statements and Section 7 concludes the paper with a discussion.

2 London Bombings

The London bombings of July 7, 2005 (also referred to as 7/7) involved 4 suicide bombers triggering explosions on the London Underground and Bus transport network. Two of these bombings took place on underground trains outside Liverpool Street and Edgeware Road stations and a third one between King's Cross and Russell Square. These bombs went off at around 8:50 in the morning during the 'rush hour' when most commuters travel to their workplaces. The fourth bomb went off on a double-decker bus at Tavistock Square about an hour later. 52 people were killed and more than 770 were injured, see [12].

3 Formalisation of Survivor Statements

Below, Section 3.1 describes how statements of survivors of the attack were obtained, and Section 3.2 explains how these were converted to formal notation.

3.1 Survivor Statements

The July 7 Review Committee was set up to ‘identify the successes and failings of the response to the bombings and to help improve things for the future…’ [12] and submitted its report to the London Assembly in June 2006. Information from nearly 85 individuals was obtained as part of this report to the London Assembly. These accounts consist of unstructured narratives from individuals involved in the incident and run into 299 pages of text. Of these, 21 are fairly detailed accounts of the experiences of the respective survivors depending on the proximity to the explosion of the concerned survivor, the evacuation process and after-effects on survivors including the psychological. 12 accounts relate to a public hearing held on 23 March 2006 and 9 relate to private meetings with the chairman of the Review Committee. The rest of the accounts consist of information provided by survivors and affected persons through email and letters.

The July 7 Review Committee also obtained information and views from nearly 40 organisations. These accounts consist of unstructured narratives and written submissions of officials from a broad range of organisations including the police, fire brigade, ambulance, hospitals, local authorities, telecommunication companies and business associations and run into 284 pages of text. For the purposes of this paper, only transcripts of individual survivors in their original form have been included in the analysis.

Statements of survivors are publicly accessible and available as a consolidated Volume 3 of the July 7 Review Report, in pdf as well as rich text format. The statements have been anonymised and so the names in the statements do not refer to the actual identity of the survivor. An example of a transcript of a survivor given the name ‘John’ and who was at the Edgeware Road Station site of the bombings, is shown in Figure 1 below.

Once again, can I thank you all for coming? John from Edgware Road, I believe you are going to start the proceedings.

John (Edgware Road): Thank you. Just after the train left Edgware station, there was a massive bang followed by two smaller bangs and then an orange fireball. I put my hands and arms over my ears and head as the windows and the doors of the carriage shattered from the blast. Splintered and broken glass flew through the air towards me and other passengers. I was pushed sideways as the train came to a sudden halt. I thought I was going to die. Horrific loud cries and screams filled the air, together with

Fig. 1. Extract from John’s transcript at the July 7 Review Committee hearing

The transcript was parsed into phrases that as far as possible conveyed a single idea leaving the statement in its original form. These phrases were treated as indications for ‘cues’ that help explain the behaviour and thoughts of the survivor. References to the location, time and elapsed time were also put alongside the cues. These have been either explicitly stated or inferred from surrounding statements in the transcript for the survivor. Each of the phrases was then formalised according to the scheme explained in the following sub-section. An extract from the parsing table for ‘John’s transcript’ is shown below in Figure 2.

John: Edgeware Road

Time and location	Cue	Belief held by survivor	Belief held by neighbour	External origin	Internal origin	Action	Thought short of action
Just after the train left Edgeware station	Just after the train left Edgeware Station, there was a massive bang, followed by two smaller bangs, then an orange fireball	Blast had occured		Explosion			
	I put my hands and arms over my ears as and head	Risk of injury Blast had occured				Protective measure	
	as the windows and doors of the carriage shattered from the blast			Shattering of windows and doors			
	Splintered and broken glass flew through the air towards me and other passengers	Risk to other passengers		Effect of blast, glass and splinters			
	I was pushed sideways as the train came to a halt			Involuntary push			
	I thought I was going to die	Going to die			Grave risk to life		
	Horrific loud cries and screams filled the air		Risk to life	Screams			

Fig. 2. Parsing table for John's transcript

3.2 Formalisation

As a first step towards formalisation of the survivor statements, a time stamp has been assigned to each cue. Since little information is known about the actual time and duration of the events, we simply used natural numbers to describe the timing of the subsequent events (i.e., we say that they took place at time point 0, 1, 2, and so on). After that, the content of the cues was analysed in more detail, to make an inventory of the classes of concepts they refer to. In general, each cue turned out to refer either to a *belief* or an *action*. Moreover, each belief or action belonged either to the *survivor* himself, or *another individual* at the scene. For example, the statement 'there was a massive bang' refers to a belief of the speaker himself (namely that a blast had occurred), whereas the statement 'I put my hands and arms over my ears and head' refers to an action of the speaker. Similarly, the statement 'a young woman sitting next to me asked me if I was OK' refers to an action of another individual. Furthermore, two types of beliefs could be distinguished, namely, beliefs that are triggered by an *external* stimulus (e.g., 'there was a massive bang') and those triggered by an *internal* stimulus or thought (e.g., 'I thought I was going to die').

Table 1. Domain Ontology

Predicate	informal meaning
has_belief(a:AGENT, b:BELIEF)	agent a has belief b
has_internal_belief(a:AGENT, b:BELIEF)	agent a has (internally triggered) belief b
performed(a:AGENT, ac:ACTION)	agent a performs action ac
Sort	**elements**
AGENT	{john, man_in_front, young_woman, …}
ACTION	{protect_head, rub_eyes, …}
BELIEF	{blast_has_occurred, risk_of_injury, …}

Based on this analysis of the content of the cues, a formal domain ontology (or signature) has been developed. For this purpose, the LEADSTO language has been used, which is an extension of order-sorted predicate logic [4]. In this language, the domain under analysis can be described in terms of sets of sorts and subsorts relations, constants in sorts, functions, and logical predicates over sorts. An overview of the domain ontology developed for the current case study is provided in Table 1.

Note that the predicates have been chosen in such a way that they can be easily mapped onto concepts in the ASCRIBE model. These predicates have generic names. The elements of the sorts are domain-specific, and depend on the particular scenario.

After development of the domain ontology, the actual formalisation of the cues was done. To this end, for each survivor, the following algorithm was executed(?) (described in pseudo-code):

```
start with an empty specification
for t = time step 1 to last-time do
  1.  determine whether the cue at time t refers to a belief (either 'internal' or
      'external') or action
  2.  determine to which agent the cue belongs
  3.  select the appropriate predicate from the domain ontology
  4.  express the cue formally using that predicate, and add the result to the
      specification, annotated with time step t
end
```

As an illustration, Figure 3(a) shows (a visualisation of) the resulting formalisation of the survivor statement that was shown in the earlier Figure 1, in an example trace. In this figure, which contains a fragment of 30 time steps, time is on the horizontal axis; a box on a line indicates that an event is true at that time point.

As a final step, the events included in the formal traces needed to be connected to concepts within the ASCRIBE model, enabling us to apply the model to the scenarios under investigation. The main concepts present in ASCRIBE are *beliefs*, *intentions*, and *emotions*, which may be related either to specific *world states* or to *decision options* (see Section 4 for details). Thus, as an example, the 'external beliefs' were translated into 'beliefs about the positiveness of the situation' and 'belief options' in ASCRIBE, the 'internal beliefs' were translated into 'emotions' (of *fear*) in ASCRIBE, and the 'actions' were translated into 'intention options' in ASCRIBE. For the belief and intention options, two types of actions were distinguished, namely 'protective actions' (e.g., covering one's ears) and 'social actions' (e.g., comforting another passenger). Moreover, during these translations, numerical values (from the set {0, 0.1, 0.2, …, 0.9, 1}, where 0.5 represents a neutral value) have been assigned to the strength of each state. For example, the belief that a blast has occurred clearly refers to a very negative situation (e.g., value 0.1), whereas the belief that help is underway refers to a positive situation (e.g., value 0.9). To guarantee inter-observer reliability, as a pre-test, part of the survivor statements have been formalised separately by two different observers. When comparing the results, the differences turned out to be small: besides minor interpretation errors, the distance between the numerical scores of the two observers never were greater than 0.2.

An example of the outcome of this final step is shown in Figure 3(b). Note that this figure corresponds to the same scenario as in Figure 3(a), but that a larger fragment (of 70 time steps) has been taken. As shown in the first graph, the positiveness of this agent (named John) fluctuates during the scenario. Initially (i.e. right after the explosion), he has some rather negative beliefs about the situation, but based on the development of the events, he starts to have some more positive beliefs from time point 20. The same pattern is repeated in the period between time point 40 and 70. Similarly, the other graphs show John's level of emotion (fear in this case), and the extent to which his actions are 'protective' or 'social' actions. Note that the graphs only show some values, that is when the information has been available; at the other time points nothing is shown. In Section 5, these kinds of information bits will be used for simulating the scenarios. In particular, the information shown in the first graph (beliefs about the situation) will be used as input for the ASCRIBE model, whereas the information from the other three graphs (emotions, protective and social actions) will be used to compare with the output of the model.

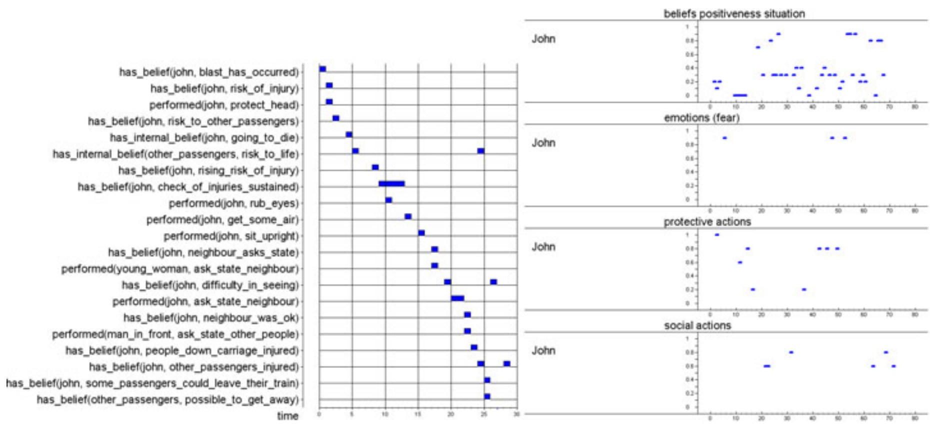

Fig. 3. Example formal trace – qualitative (a) and quantitative (b) information

4 Simulation Model

To simulate the dynamics of beliefs, emotions and intentions of individuals involved in the 7/7 London bombings of 2005, the agent-based model ASCRIBE [9] was used and implemented in Matlab. For a complete overview of ASCRIBE, see [9]. In this section, the model is only briefly summarised and explained in terms of how it was tailored to the 7/7 London bombings case. The main concepts present in the original ASCRIBE model [9] are *beliefs*, *intentions*, and *emotions*. For the current purpose, the following specific states for the agents were taken, namely 1 emotional state per agent (fear), 2 intentional states per agent (either to perform a protective or social action) and 3 beliefs (one about the 'positiveness' of the situation and two about whether an agent should perform a protective or social action):

fear of agent A	$q_{fearA}(t)$
intention indication for action option O of agent A	$q_{intention(O)A}(t)$
belief in X (either about situation or action) of agent A	$q_{belief(X)A}(t)$

In Figure 4, which is adapted from [9], an overview of the interplay of these different states within the model is shown. It is assumed that at the individual level the strength of an intention for a certain action option depends on the person's beliefs (*cognitive* *responding*) in relation to that option. It is also assumed that beliefs may generate certain emotions (*affective responding*), for example that of fear, that in turn may affect the strength of beliefs (*affective biasing*). Note that it is assumed that these latter emotions are independent of the different action options. The contagion of all the different states between individuals is based on the concept of a *mirror neuron* (e.g., [10,11]) in Neuroscience. When states of other persons are mirrored by some of the person's own states, which at the same time play a role in generating their own behaviour, then this provides an effective basic mechanism for understanding how in a social context, individuals affect each other's mental states and behaviour.

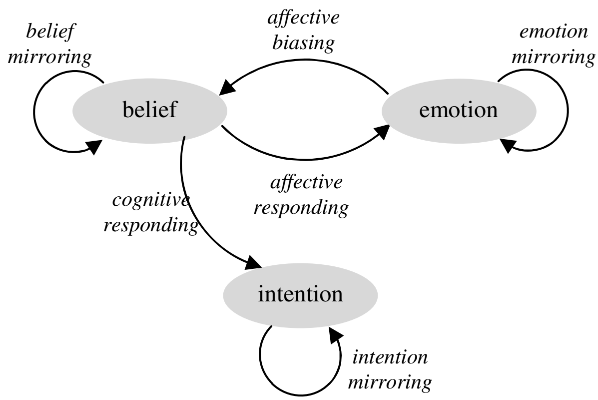

Fig. 4. The interplay of beliefs, emotions and intentions in the 7/7 London bombings context

Note that all mirroring processes take place through interaction between agents, whereas the other processes shown in Figure 4 occur internally, within an individual agent. An overview of the different intra- and interpersonal interaction processes is given in Table 2.

Table 2. The different types of processes in the model

from ***S***	**to** ***S'***	**type**	**description**
belief(X)	*fear*	internal	affective response on information; for example, on threats and possibilities to escape
fear	*fear*	interaction	emotion mirroring by nonverbal and verbal interaction; for example, fear contagion
fear	*belief(X)*	internal	affective biasing; for example, adapting openness or expressiveness
belief(X)	*belief(X)*	interaction	belief mirroring by nonverbal and verbal interaction; for example, of information on threats and action options
belief(X)	*intention(O)*	internal	cognitive response on information; for example, aiming for a protective action based on the danger of the situation
intention(O)	*intention(O)*	interaction	intention mirroring by nonverbal and verbal interaction; for example, of tendency to aim for a social action

The central idea of the model is based upon the notion of contagion strength γ_{SBA} which is the strength with which an agent B influences agent A with respect to a certain mental state S (which, for example, can be an emotion, a belief, or an intention). It depends on the *expressiveness* (ε_{SB}) of the sender B, the strength of the *channel* (α_{SBA}) from sender B to receiver A and the *openness* (δ_{SA}) of the receiver: $\gamma_{SBA} = \varepsilon_{SB}\ \alpha_{SBA}\ \delta_{SA}$. The level q_{SA} for mental state S of agent A is updated using the overall contagion strength of all agents B not equal to agent A: $\gamma_{SA} = \Sigma_{B \neq A}\ \gamma_{SBA}$. Then the weighed external impact q_{SA}*: for the mental state S of all the agents B upon agent A, is determined by: $q_{SA}{}^* = \Sigma_{B \neq A}\ \gamma_{SBA}\ q_{SB} / \gamma_{SA}$. Then, state S for an agent A is updated by:

$$q_{SA}(t+\Delta t) = q_{SA}(t) + \psi_{SA}\ \gamma_{SA}\ [f(q_{SA}{}^*(t), q_{SA}(t)) - q_{SA}(t)]\ \Delta t \tag{1}$$

Here ψ_{SA} is an update speed factor for S, and $f(V_1, V_2)$ a combination function. This expresses that the value for q_{SA} is defined by taking the old value, and adding the change term, which basically is based on the difference between $f(q_{SA}{}^*(t), q_{SA}(t))$ and $q_{SA}(t)$. The change also depends on two factors: the overall contagion strength γ_{SA} (i.e., the higher this γ_{SA}, the more rapid the change) and the speed factor ψ_{SA}.

Within the definition of the combination function $f(V_1, V_2)$ a number of further personality characteristics determine the precise influence of the contagion. First, a factor η_{SA} is distinguished which expresses the tendency of an agent to absorb or amplify the level of a state S, whereas another personality characteristic β_{SA} represents the bias towards reducing or increasing the value of the state S. Thus, the combination function $f(V_1, V_2)$ is defined as follows:

$$f(V_1, V_2) = \eta_{SA}\ [\ \beta_{SA}\ (1 - (1 - V_1)(1 - V_2)) + (1-\beta_{SA})\ V_1 V_2\ ] + (1 - \eta_{SA})\ V_1 \tag{2}$$

In the ASCRIBE model, the effects of emotions on beliefs are calculated with the formulae in Section 4.1 of [9]. Instead of using these formulae here, the values for beliefs about the situation and action options were taken from the empirical data as explained in Section 2 and 3. Here, we assume the effects of emotions on beliefs are implicitly present in these input values.

The effect of the emotion fear on beliefs is expressed by the following formula:

$$\begin{aligned} q_{fear,A}{}^*(t) = \nu_A \cdot (\Sigma_{B \neq A}\ \gamma_{fearBA} \cdot q_{fearB} / \gamma_{fearA}) + \\ (1 - \nu_A) \cdot (\Sigma_X\ \ \omega_{X,fear,A} \cdot (1 - p_{XA}) \cdot r_{XA} \cdot q_{belief(X)A}) \end{aligned} \tag{3}$$

In formula 3, information has an increasing effect on fear if it is relevant and non positive, through informational state characteristics r_{XA} denoting how relevant, and p_{XA} denoting how positive information X is for person A. The influence depends on the impact from the emotion fear by others (the first factor, with weight ν_A) in combination with the influence of the belief present within the person. This $q_{fear,A}{}^*(t)$ is used in the equation describing the dynamics of fear:

$$q_{fearA}(t+\Delta t) = q_{fearA}(t) + \gamma_{fearA}\ [f(q_{fearA}{}^*(t), q_{fearA}(t)) - q_{fearA}(t)]\ \Delta t$$

with

$$f(q_{fearA}{}^*(t), q_{fearA}(t)) = \eta_{fearA}\ [\beta_{fearA}\ (1 - (1 - q_{fearA}{}^*(t))(1 - q_{fearA}(t))) + (1-\beta_{fearA})\ q_{SA}{}^*(t)\ q_{SA}(t)]$$
$$+ (1 - \eta_{fearA})\ q_{fearA}{}^*(t)$$

Furthermore, the specific state $q_{emotion(O)A}$ was left out of the current model, since this state was not mentioned in the survivor reports and it is not realistic to use in these simulations. Therefore, the effect of emotions on intentions in ASCRIBE is left out in the current model, leaving the effect of beliefs on intentions calculated as follows:

$$q_{beliefsfor(O)A}(t) = \Sigma_X\ \ \omega_{XOA}\ q_{belief(X)A} / \Sigma_X\ \ \omega_{XOA}$$

where ω_{XOA} indicates how supportive information X is for option O. The combination of the group's aggregated intentions with an agent's own belief for option O is made by a weighted average of the two:

$$q_{intention(O)A}^{**}(t) = (\omega_{OIA}/\omega_{OIBA})q_{intention(O)A}^{*}(t) + (\omega_{OBA}/\omega_{OIBA})\, q_{beliefsfor(O)A}(t) \tag{4}$$

$$\gamma_{intention(O)A}^{*} = \omega_{OIBA}\ \gamma_{intention(O)A} \tag{5}$$

where ω_{OIA} and ω_{OIBA} are the weights for the contributions of the group intention impact (by mirroring) and the own belief impact on the intention of A for O, respectively, and

$$\omega_{OIBA} = \omega_{OIA} + \omega_{OBA}$$

The overall model for the dynamics of intentions for options becomes:

$$\begin{aligned} q_{intention(O)A}(t + \Delta t) = {} & q_{intention(O)A}(t) + \gamma_{intention(O)A}^{*}\,[\eta_{intention(O)A}\,(\beta_{intention(O)A}\,(1 - (1 - \\ & q_{intention(O)A}^{**}(t))(1 - q_{intention(O)A}(t))) + (1 - \beta_{intention(O)A})\, q_{intention(O)A}^{**}(t)\ q_{intention(O)A}(t)) \\ & + (1 - \eta_{intention(O)A})\, q_{intention(O)A}^{**}(t) - q_{intention(O)A}(t)] \cdot \Delta t \end{aligned} \tag{6}$$

5 Simulation Results

Multiple survivor reports of the London bombings at 7-7-2005 were formalised, as described in Section 2 and 3. As an illustration, in this section the simulation results of the ASCRIBE model for one particular instance of this data is shown, namely for the scenario described in Section 3, involving the survivor named John. In the survivor report of John, the beliefs, emotions and intentions of 3 other persons were mentioned as well, therefore the simulation in Matlab was made for 4 agents in total. The beliefs of the situation and for the two action options (social action or protective action) were taken as inputs of the model. The fear value of John, and the values for his intentions to act in a protective or social manner, were produced by the ASCRIBE model as outputs. These output values (all between 0 and 1) are shown in Figure 5 and can be compared to the emotion fear and social and protective actions stated in the survivor report, which were formalised and are shown in Figure 3(b). The patterns in Figure 5, outputted by the ASCRIBE model, correspond quite well with the patterns in the formalised empirical data from the survivor report in Figure 3(b). For example, in Figure 3(b) it can be seen that survivor John had a high fear level of 0.9 at three points in his report. In the left graph in Figure 5 it can be seen that through the interactions with the other agents and the internal affective responding, agent John also has a high fear value, fluctuating between 0.7 and 0.9. The right graph in Figure 5 shows that at the beginning, John aims more for protective actions than social actions, which seems the logical thing to do in a dangerous situation. Over all time steps, John shows a decrease in his aiming for protective actions in the first 10 time steps, followed by an increase till time step 15 and than another decrease till time step 30. This pattern can also be seen in Figure 3(b), where John's stated protective actions in his report started high, then decreased, increased and finally decreased. In Figure 3(b) it can also be seen that John stated that he performed social actions, formalised by the value 0.6, around time steps 20-25 and 60-70. Figure 5 shows that the ASCRIBE model as well outputs social actions around the value 0.6, around time steps 20-25 and 60-70. The difference between Figure 3(b) and Figure 5 is, that in Figure 5 all values change dynamically over time, they are continuous, and in Figure 3(b) the values are only available for certain points in time, taken from the survivor report. As a consequence, the total pattern of the real world data is not directly visible in the formalisation, like in Figure 3(b), but is visible when simulated by the ASCRIBE model. To further validate the ASCRIBE model against the real world data, a formal check was performed, where the real world data and the simulation results from the ASCRIBE model were compared automatically. This is explained in the next section.

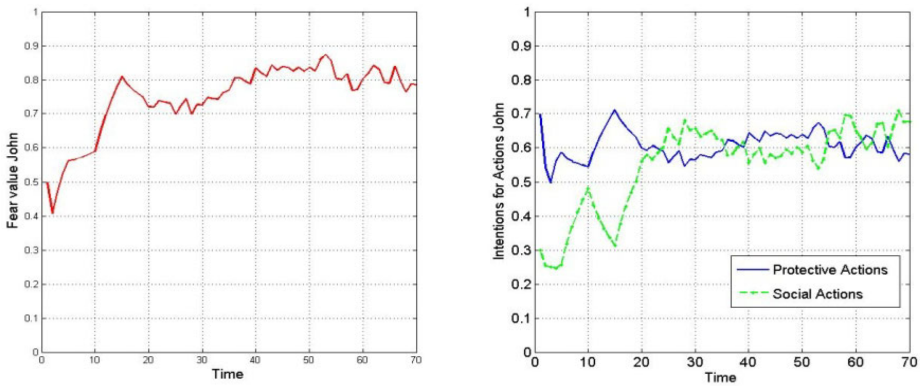

Fig. 5. The values for fear and intentions for actions of survivor John

6 Formal Comparison

To formally compare the simulation results in Section 5 with the formalised transcripts presented in Section 3.2, the TTL Checker Tool [3] has been used. This piece of software enables the researcher to check whether certain expected (dynamic) properties, expressed as statements in the Temporal Trace Language (TTL) [3], hold for a given *trace* (defined as a time-indexed sequence of states). Since the tool can take both simulated and empirical traces as input, it can be used to check (automatically) whether the generated simulation runs show similar patterns to the real world transcripts.

Using the TTL Checker Tool, a number of dynamic properties have been verified against the traces described in Section 3.2 and 5 (which we will refer to as *empirical traces* and *simulation traces*, respectively). Some of these properties are presented below. To enhance readability, they are represented here in an informal notation, instead of a formal TTL notation. Note that the letters mentioned in the round brackets are parameters, which can be filled in when checking the property using the Checker Tool.

P1(a:agent, i1,i2:interval, m:trace) - 'More positiveness implies more social actions'
For intervals i1 and i2 within trace m, if the average positiveness of agent a's beliefs about the situation is higher in i1 than in i2, then agent a will perform more social actions in i1 than in i2.

P2(a:agent, i1,i2:interval, m:trace) - 'More positiveness implies less protective actions'
For intervals i1 and i2 within trace m, if the average positiveness of agent a's beliefs about the situation is higher in i1 than in i2, then agent a will perform more protective actions in i2 than in i1.

These dynamic properties (among several others, which are not shown due to space limitations) have been checked against the empirical and the simulation traces (where for all agents a, the interviewed persons were filled in). To create the intervals, all traces have been split up into relevant sub-scenarios (e.g., a part in which a person is present within a train carriage, or is present outside the train), and each sub-scenario has been cut into two equal halves, which we call intervals. Thus, by checking property P1 and P2 for all sub-scenarios, we basically checked whether it was the case that people who became more positive during a sub-scenario stopped protecting themselves and started to help others, and vice versa. Surprisingly, this property turned out to hold for almost all sub-scenarios of the empirical traces. This is an interesting finding, which can be potentially explained by the phenomenon that positive people are more open to external stimuli [8]. In addition, the property holds true for the simulated traces for the exact same sub-scenarios as in the empirical traces. Although this is obviously not an exhaustive proof of the correctness of the ASCRIBE model, it illustrates that the model can be used to reproduce similar patterns found in realistic scenarios.

7 Discussion

In this paper, it has been shown how the dynamics of individuals' mental states in a real world emergency can be analysed, through formalising survivor reports of the 7/7 London bombings in 2005 and evaluating them against generated simulations of the same case study with the ASCRIBE model. It is quite rare to work with this type of real world data of survivors of a terroristic attack. Nevertheless, the ASCRIBE simulations in Section 5 showed that it can simulate corresponding patterns in the empirical data of the 7/7 London bombings. The formal check of dynamic properties in Section 6 also shows that the ASCRIBE model can be used to reproduce similar patterns found in emergency scenarios, as in evacuation after a terrorist attack.

So far, the results show that the ASCRIBE model can reproduce patterns in the dynamics of beliefs, intentions and emotions of people involved in a terroristic attack in the real world. The results are promising, and although the transcription work is quite time consuming, the current analysis model has been set up in a generic manner, which means large parts can be re-used for the analysis of other real world incidents or disasters.

The current paper should mainly be seen as a proof-of-concept. The methodology turns out to be applicable to analysis of parts of the 7/7 bombings case study. In future work, the authors intend to analyse reports of a larger number of survivors, and to address more and different case studies, thereby better testing the robustness of the model. In addition, a more extensive evaluation is planned, using a quantitative measure for the correctness of the simulation results.

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